Agrivoltaics in regional planning - an integrated assessment framework

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Abstract **– The expansion of renewable energies often faces trade-offs with other objectives such as food security and biodiversity. Agrivoltaics (APV) is a dual-land use system mitigating this trilemma by allowing for the production of electricity and agriculture on the same location. Yet, while it is politically desired it requires adequate regional planning. Using the Stuttgart Region as a case study, we developed an integrated assessment framework to identify potential priority APV sites on arable land. Agricultural income, nature conservation, landscape aesthetics and power feed-in are used as weighted criteria in an optimization model. Especially the agricultural income decreases with increasing expansion of APV. Also prioritising landscape aesthetics leads to higher income losses for agriculture. The framework is useful for subsequent research like scenario analysis with relevant stakeholders.**

INTRODUCTION

The transformation towards a carbon neutral energy supply is particularly relevant to mitigate climate change and reducing the dependency of fossil resources, which also requires a considerable expansion of photovoltaics. Ground-mounted photovoltaics are often related with farmland consumption and associated conflicts, for instance with agriculture (Trommsdorff et al., 2020). In this context, agrivoltaics (APV) could be one solution to overcome conflicts of interest and to improve land use efficiency (Schindele et al., 2020). Although, the technology is rarely implemented in Germany (Trommsdorff et al., 2020), it is politically desired on arable land in particular, however, not on grassland for nature conservation reasons (Die Bundesregierung, 2022). APV thus must be also addressed in regional planning, which requires consideration of conflicting goals, e. g. nature conservation objectives or acceptance by society, i. e., impacts on landscape aesthetics (Trommsdorff et al., 2020). In this context, we provide an integrated assessment framework to support the consideration of APV in regional planning at the example of arable land in the Stuttgart Region in Germany. Grassland is excluded. We aim to identify priority APV sites and to show potential conflicts between four different criteria for regional APV expansion.

MATERIAL AND METHODS

For analysis we use the system design of the research APV plant in Heggelbach (Germany) with an installed capacity of 0.52 MWp per ha as example (Schindele et al., 2020). In the first step we identified areas that disable implementation of APV in cooperation with the regional planning unit ("Verband Region Stuttgart"), a catalogue of criteria for ground-mounted solar systems by LUBW (2021a) and we excluded areas with an average slope above 7% (oral information from Mr. Schindele, BayWa AG, 15.11.2021). 37% of arable land were considered as not suitable for APV at all (LUBW, 2021b; BKG, 2021a; BKG, 2021b).

All remaining arable field plots (n=49,492) were then assigned a score between 1 and 10 for the criteria: agricultural income, nature conservation, landscape aesthetics and power feed-in possibility. In case of agricultural income, the region was divided into pixels of 100 ha and each plot within a pixel was assigned the observed crop share of the pixel from the Integrated Administration and Control System 2021 as well as a yield capacity (low, medium, high) according to LGRB (2015). Annual gross margin changes (GM) were calculated by plot for implementing APV (LEL, 2021; LfL, 2021; KTBL, 2021). Therefore, assumptions were made about changes in crop yields due to shading (e. g. -33.4% in winter wheat) and crop management costs (+2% variable machine costs), as well as a 8% area loss of 8% caused by APV (Laub et al., 2021; Artru et al., 2018; Trommsdorff et al., 2016). Finally, plots with no GM reduction were given a score of 1, plots with a reduction of more than 800 € per ha were given a score of 10, i. e. increase of 1 per 100 € GM loss. For nature conservation, we used a map showing areas with particularly high values for extensive arable farming, thus having a high suitability for nature conservation. (Sponagel et al., 2021). We have assumed that land suitability for APV decreases with increasing nature conservation value. For this criteria the plots received a value between 1 (lowest value) and 10 (highest value). To assess landscape aesthetics we used the map from Roser (2014), which assigns field plots a value from 0 to 10, where 0 and 1 were aggregated to the score 1. To evaluate the possibility for power feed-in, the distance between plots and the closest commercial area was calculated (BKG 2021a). Scores were assigned from 1 to 10 in steps of 500 m. The scores by criteria and plot were summed with equal weights. In the objective function of a linear programming model, the APV area per plot was multiplied by the total plot score. For a given APV capacity the sum over all plots was minimised. In addition, food production was assessed in cereal units.

RESULTS

Figure 1 shows the development of the average scores by criteria of the APV plots with increasing installed capacity. Up to an installed capacity of 10 GWp (27% of arable land in the region), the average score for power feed-in remains rather low up to 1.75 (< 1 km distance). The average scores for landscape aesthetics and nature conservation seem to be rather close to each other between 3 and 3.6. The

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development of the score for agriculture is worth highlighting. Up to a capacity of 3 GWp, this increases sharply to a score of around 6, which means GM reductions between 400 and 500 € per ha. Only up to an expansion of about 0.2 GWp the score for agriculture is up to 2, which would mean GM changes up -100 € per ha-.The implementation of APV also impacts food supply: from -0.8% for 1 GWp up to -9% for 10 GWp.

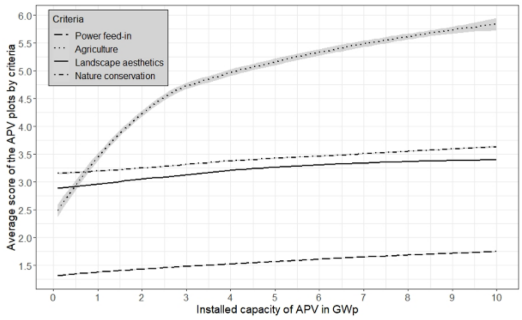

Figure 1. Development of the average score per subject with increasing installed capacity of APV.

If plots with a score greater than 2 for landscape aesthetics are not considered for APV, the expansion of APV is limited to 2 GWp and the average score for agriculture increases up to 7.4 (+70%), which means about 300 € higher average GM losses per ha. The average scores for nature conservation and energy feed-in just increase by 26% and 33%. In addition, a change in spatial distribution of the APV areas can be observed as shown for 1 GWp APV in Figure 2.

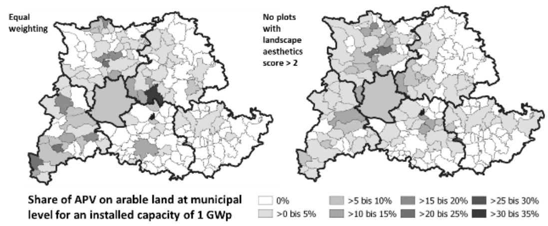

Figure 2. Share of arable land with APV at municipal level with and without landscape aesthetics prioritisation (BKG, 2022).

Discussion and Conclusions

We provided a framework for an integrated assessment of arable land for the implementation of APV. Under the assumption of equal criteria weighting average scores for nature conservation and landscape aesthetics are rather on a moderate level up to 10 GWp installed capacity. In particular, agricultural income declines with increasing expansion of APV.

When interpreting the results, however, some limitations of the applied approach should be kept in mind. This refers to selected criteria and score assignment. Changes in GMs were calculated in a simplified manner, i. e. crop rotation adjustments were not considered. This should be done in a next step. Our results are particular relevant for decision makers in the field of regional planning and help to identify priority areas for APV. Subsequent research should refine the approach, in particular with formation of scenarios with the relevant stakeholders or transfer to other regions.

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